

# Analysis of helminth communities of the pine marten, *Martes martes*, in Spain: Mainland and insular data

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## Abstract

The present study analyses the helminth communities found in one hundred and two specimens of *Martes martes* from the Iberian Peninsula and the Balearic Archipelago. The component community is constituted by seventeen helminth species, which frequency and mean abundance show a bimodal pattern. The set of core species is constituted by the trichurids *Pearsonema plica*, *Eucoleus aerophilus* and *Aonchotheca putorii* (72.2% of total helminth individuals found), while the remaining can be considered satellite species. Significant co-occurrences were found among *E. aerophilus*/*A. putorii* and *E. aerophilus*/*P. plica*. These results demonstrate the great importance of earthworms within the diet of pine marten and contribute to the knowledge of the pine marten's food ethology, since this kind of prey normally goes undetected in diet studies. Several helminth species, as *Sobolevinygylus petrowi*, *Centrorhynchus aluconis*, *Uncinaria criniformis*, *Mastophorus muris* and *Spirura rytipleurites seu-rati* seem to show geographical distributions limited to insular ecosystems. Moreover, helminth communities of *M. martes* among four Spanish territories, including mainland and insular areas, are characterized and compared.

## Key words

Helminth community, *Martes martes*, Mustelidae, Carnivora, insularity, Spain

## Introduction

According to Wilson and Reeder (1993), there are eight species in the genus *Martes* Pinel, 1792: *M. americana* (Turton, 1806), *M. flavigula* (Boddaert, 1875), *M. foina* (Erxleben, 1777), *M. gwatkinsii* Hortfield, 1851, *M. martes* (Linnaeus, 1758), *M. melampus* (Wagner, 1841), *M. pennati* (Erxleben, 1777) and *M. zibellina* (Linnaeus, 1758). The pine marten, *M. martes*, is a species widely distributed in Europe that can be found not only from the Iberian Peninsula to the Urals and the Caucasus, but also in the British Isles. Its western continental distribution is located in the northern third of the Iberian Peninsula where it lives restricted to forested environments of Euro-Siberian type, commonly covered with snow. *Martes martes* is also found on several Mediterranean islands, including the Gymnesic (Majorca and Minorca) of the Balearic Archipelago, where it has adapted to moderate temperatures and zones where snow is unusual.

Parasitological studies on *M. martes* are usually concerned about certain harmful helminths, mainly of the genus *Tri-*

*chinella* Railliet, 1895; *Filaroides* Van Beneden, 1858; *Uncinaria* Froelich, 1789; *Angiostrongylus* Kamensky, 1905 and *Skrjabingylus* Petrow, 1927 (Hansson 1968, Fameree *et al.* 1981, Kankava *et al.* 1983, Hirvela-Koski *et al.* 1985, Yanchev 1986, Jancev and Genov 1988, Kulikova and Yaluga 1989, Pozio 1995, Romashov 2001, Senutaite and Grikieniene 2001, Koubek *et al.* 2004). However, faunistic and ecological studies on the helminth fauna of *M. martes* are scarce, being mainly originate from Central or Eastern Europe (Sołtys 1962, Shakhmatova 1966, Yushkov 1982, Priemer and Tscherner 1997). Thus, until now there has been a lack of knowledge on the helminth fauna of *M. martes* from Western Europe. Furthermore, no studies concerning the parasitological aspects of any mustelid inhabiting Mediterranean islands have been published to date.

The aim of the present study was to provide the first qualitative and quantitative data of the helminth fauna of *M. martes* in Western Europe. In addition, helminth component communities of pine martens in four Spanish territories were characterized, among which, the inclusion of Majorca and Mi-

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norca allowed us to evaluate the influence of insularity over the mustelid's helminth fauna.

## Materials and methods

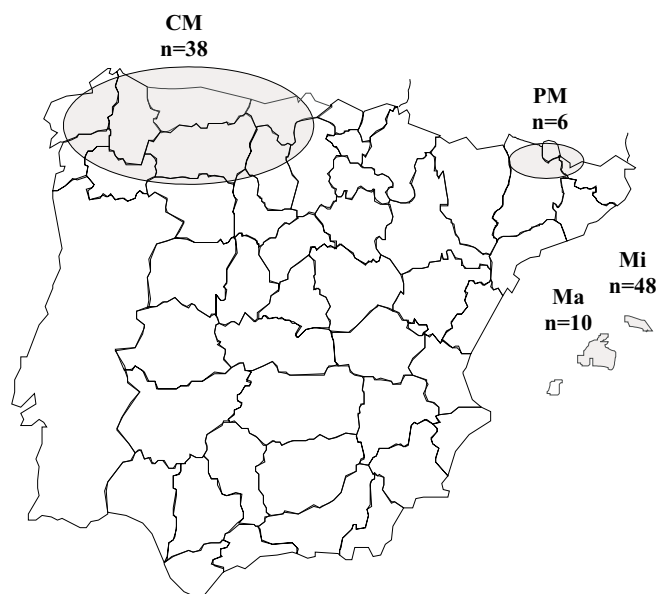
One hundred and two specimens of *M. martes* from the Iberian Peninsula and the Balearic Archipelago were analysed (see Fig. 1). The Iberian individuals came from the Cantabrian Mountains (CM;  $n = 38$ ) and the Pyrenean Mountains (PM;  $n = 6$ ). The insular samples came from Majorca (Ma;  $n = 10$ ) and Minorca (Mi;  $n = 48$ ). The Cantabrian Mountains extend for 300 km and cover around 18,000 km<sup>2</sup>. This zone ranges from 600 to 2,500 m asl and shows a continental climate, with mean temperatures ranging between 0°C and 18°C. The prospected area of the Pyrenean Mountains is located in the province of Lleida and covers about 3,000 km<sup>2</sup>, including the highest summits of the range (Aneto, in the Maladetta ridge with 3,404 m asl). The island of Minorca, located approximately 250 km from the peninsula, is the northern most and the second largest island of the archipelago, covering around 700 km<sup>2</sup>. Its climate is typically Mediterranean with moderate temperatures ranging between 10°C and 26°C. Majorca, located at 37 km from Minorca, is the biggest island of the Balearic Archipelago, with an area of 3,640 km<sup>2</sup>. The island is limited by the mountain ranges of Tramuntana and Levante in the northeast and southeast, respectively.

Official Institutions provided all the hosts for this survey. All host specimens were preserved in 70% ethanol or 10% formaldehyde until the helminthological analysis. Viscera of each carcass were examined in accordance with general hel-

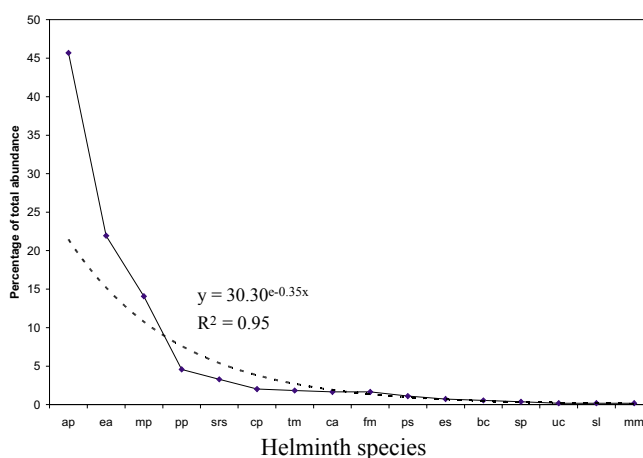
minthological methods. A sample of diaphragm muscle from each specimen was analysed by trichinelloscopy. All helminths were counted and identified following specialized protocols for each species. Helminths were preserved in 70% ethanol in the collection of the "Laboratori de Parasitologia" at the University of Barcelona. Voucher specimen numbers were deposited under code JMS:ES1-102.

Differences between parasite populations were evaluated by using several statistical tests. Chi square was used to compare prevalence data. ANOVA and post hoc tests (for species richness) and Kruskal-Wallis  $H$  and Mann-Whitney  $U$ -tests (for abundances) were used to evaluate significance in the comparisons between samples. Significant co-occurrences among species were analysed by means of McNemar test. The non-parametric rho-Spearman test was used to evaluate correlations between frequency and abundance data. Significance level was taken at  $\alpha = 0.05$ , unless otherwise specified. All statistical tests were calculated using SPSS for Windows v.10.0. Distribution of helminth species among hosts was studied by calculating the coefficient of dispersion (variance/mean). The structure of the component community was studied by analysing distribution of mean abundance and frequency data for species found. The percentage of total abundance was calculated for each helminth species in order to estimate a function which better describes the distribution of abundance data in general sample.

The diversity of helminth communities in each host sub-population was examined by calculating the diversity indexes of Margalef, Shannon, Simpson and Berger Parker. The similarities between helminth infracommunities were also studied by calculating the indexes of Jaccard and Sorenson, as well as the quantitative measures of Sorenson and Morisita-Horn (modified version of Wolda), in accordance with Magurran (1989). A cluster analysis was carried out in order to evaluate similarities between component communities of helminths found, using the Jaccard coefficient and group average linkage. The ecological terminology follows Bush *et al.* (1997).



**Fig. 1.** Origin of individual *Martes martes* ( $n = 102$ ) analysed in the present study. CM – Cantabrian Mountains, PM – Pyrenean Mountains, Ma – Majorca, Mi – Minorca



**Fig. 2.** Distribution of abundance data for helminth species found in *Martes martes* ( $n = 102$ ). Abundance of *Trichinella* species was not considered. The interrupted line represent the exponential function

## Results

Helminths recovered from the whole sample included seventeen species: *Euryhelminis squamula* (Rudolphi, 1819) (Trema-

toda); *Taenia martis* (Zeder, 1803) (Cestoda); *Pearsonema plica* (Rudolphi, 1819), *Eucoleus aerophilus* (Creplin, 1839), *Aonchotheca putorii* (Rudolphi, 1819), *Trichinella* sp., *Uncinaria criniformis* (Goeze, 1782), *Molineus patens* (Dujardin,

**Table I.** Quantitative data of helminth species found in general sample (n = 102). Data of *Trichinella* sp. corresponds to a subsample of n = 90 diaphragms analysed

	Specificity	P(%)	MI ± SE	MA ± SE	Coefficient of distribution
<b>Trematoda</b>					
<i>Euryhelminis squamula</i>	G/M	0.98	4	0.04 ± 0.40	–
<b>Cestoda</b>					
<i>Taenia martis</i>	S	5.88	1.76 ± 1.21	0.10 ± 0.50	0.88
<b>Nematoda</b>					
<i>Pearsonema plica</i>	G	12.74	1.92 ± 1.89	0.25 ± 0.92	1.86
<i>Eucoleus aerophilus</i>	G	50.98	2.30 ± 2.01	1.18 ± 1.84	1.76
<i>Aonchotheca putorii</i>	S	21.57	11.36 ± 15.06	2.45 ± 8.32	19.96
<i>Trichinella</i> sp.	G/M	4.44	0.65 ± 4.21	0.57 ± 3.96	17.41
<i>Uncinaria criniformis</i>	S	0.98	1	0.01 ± 0.01	–
<i>Molineus patens</i>	G/M	9.80	7.70 ± 11.37	0.75 ± 4.10	16.80
<i>Crenosoma petrowi</i>	S	7.84	1.37 ± 0.74	0.11 ± 0.42	0.40
<i>Sobolevius petrowi</i>	S	1.96	1 ± 0	0.02 ± 0.14	0
<i>Filaroides martis</i>	S	3.92	2.25 ± 1.89	0.09 ± 0.55	1.59
<i>Baylisascaris columnaris</i>	G	2.94	1 ± 0	0.03 ± 0.17	0
<i>Spirocerca lupi</i>	G	0.98	1	0.01 ± 0.10	–
<i>Mastophorus muris</i>	G/M	0.98	1	0.01 ± 0.10	–
<i>Spirura rytipleurites seurati</i>	G/M	1.96	9 ± 11.31	0.18 ± 1.69	14.22
<i>Physaloptera sibirica</i>	G	1.96	3 ± 2.83	0.06 ± 0.50	2.67
<b>Acanthocephala</b>					
<i>Centrorhynchus aluconis</i>	G	2.94	3 ± 2.65	0.09 ± 0.63	2.33

**Table III.** Species richness and diversity indexes for helminth communities in four geographical areas prospected

	Cantabrian Mountains	Pyrenean Mountains	Minorca	Majorca
Species richness	11	8	8	5
Margaleff	6.86	8.24	24.73	7.05
Shannon ( $H'$ )	1.04	1.68	0.71	1.15
Simpson ( $D$ )	0.49	0.09	0.37	0.33
Inverse of Simpson ( $1/D$ )	2.04	11.59	2.71	3.00
Berger-Parker ( $d$ )	0.73	0.40	0.84	0.60
Inverse of Berger-Parker ( $1/d$ )	1.37	2.47	1.19	1.68

**Table IV.** Similarity indexes for the helminth communities studied

Samples compared	Common species	Jaccard	Sorenson quantitative	Sorenson	Morisita-Horn
CM-Ma	2	0.143	0.250	0.143	0.114
CM-Mi	5	0.357	0.526	0.190	0.149
CM-PM	7	0.583	0.737	0.287	0.250
PM-Ma	1	0.083	0.154	0.068	0.020
PM-Mi	4	0.333	0.500	0.185	0.200
Mi-Ma	2	0.182	0.308	0.121	0.111

**Table II.** Quantitative data of helminth species found in areas studied. Intensity values of *Trichinella* species (marked with asterisk in the table) indicate the mean number of larvae per gram of tissue

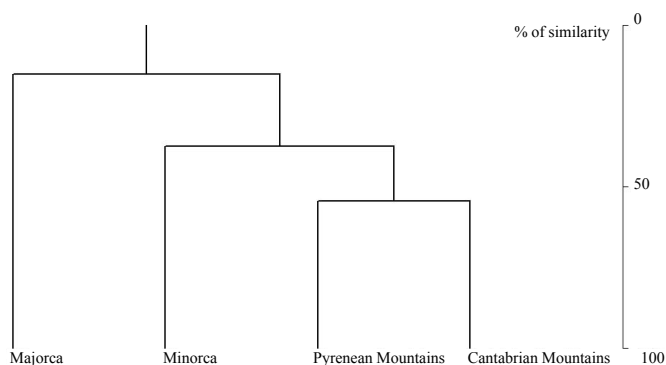
	Iberian Peninsula (n = 44)				Pyrenean Mountains (PM)				Balearic Archipelago (n = 58)			
	Cantabrian Mountains (CM)		(n = 38)		(n = 6)		(n = 48)		(n = 10)		(n = 10)	
	P	MI ± SE	MA ± SE	P	MI ± SE	MA ± SE	P	MI ± SE	MA ± SE	P	MI ± SE	MA ± SE
<b>Trematoda</b>												
<i>E. squamula</i>	2.63	4	0.11 ± 0.65									
<b>Cestoda</b>												
<i>T. martis</i>	5.26	1 ± 0	0.53 ± 0.23	17	4	0.67 ± 1.63	6.52	1.33 ± 0.58	0.08 ± 0.35			
<b>Nematoda</b>												
<i>P. plica</i>	13	1 ± 0	0.13 ± 0.34	83	3.00 ± 2.83	2.50 ± 2.81	6.52	1.67 ± 0.58	0.10 ± 0.42			
<i>E. aerophilus</i>	34	2.68 ± 2.50	0.92 ± 1.92	50	1.67 ± 1.15	0.83 ± 1.17	65	2.39 ± 1.99	1.54 ± 1.97	50	1.20 ± 0.45	0.60 ± 0.70
<i>A. putorii</i>	50	12.95 ± 15.66	6.47 ± 12.74	33	1.50 ± 0.71	0.50 ± 0.84	2.08	1	0.02 ± 0.14			
<i>Trichinella</i> sp.	10	1.31 ± 6.44*		16.67	3.18 ± 7.80*							
<i>U. crinitiformis</i>							2.08	1	0.02 ± 0.14			
<i>M. patens</i>	13	5.40 ± 7.70	0.71 ± 3.14							50	10.00 ± 14.78	5.00 ± 11.18
<i>C. petrowi</i>	18	1.43 ± 0.79	0.26 ± 0.64				2.08	1	0.02 ± 0.14	20	1 ± 0	0.20 ± 0.42
<i>S. petrowi</i>												
<i>F. martis</i>	5.26	1.50 ± 0.71	0.08 ± 0.36	33	3.00 ± 2.83	1.00 ± 2.00						
<i>B. columnaris</i>				50	1 ± 0	0.50 ± 0.55						
<i>S. lupi</i>	2.63	1	0.03 ± 0.16									
<i>M. muris</i>												
<i>S. r. seurati</i>							2.08	1	0.02 ± 0.14			
<i>P. sibirica</i>	2.63	5	0.13 ± 0.81	17	1	0.17 ± 0.41	2.08	1	0.02 ± 0.14	10	17	1.70 ± 5.38
<b>Acanthocephala</b>												
<i>C. aluconis</i>										30	3.00 ± 2.65	0.90 ± 1.91

1845), *Crenosoma petrowi* Morozov, 1939, *Sobolevinygylus petrowi* Romanov, 1952, *Filaroides martis* (Werner, 1783), *Baylisascaris columnaris* (Leidy, 1856), *Spirocerca lupi* (Rudolphi, 1809), *Mastophorus muris* (Gmelin, 1790), *Spirura rytipleurites seurati* Chabaud, 1954, *Physaloptera sibirica* Petrow et Gorbunow, 1931 (Nematoda) and *Centrorhynchus aluconis* (Müller, 1780) (Acanthocephala). Data on prevalence, mean intensity, mean abundance, coefficient of distribution and host-specificity for all helminth species found (in respect of the Mustelidae family) are shown in Table I.

Concerning general sample, 74.5% of analysed hosts were found to be parasitized by helminths. The prevalence was 0.98% for trematodes, 5.88% for cestodes, 72.5% for nematodes, and 2.9% for acanthocephalans. Each individual pine marten harboured a mean of 1.28 species (SD = 1.13, range = 0–5) and a mean of 5.36 single helminths (SD = 0.65, range = 0–56). Analysing data of abundance revealed a pattern of distribution which fits quite well an exponential function ( $y = 30.3e^{-0.35x}$ ;  $R^2 = 0.95$ ) (Fig. 2). In general, the most abundant species were those that showed the highest prevalence (rho-Spearman = 0.73;  $p < 0.01$ ).

More than one-third of helminths found (35.3%) are specific to mustelids, while the rest are generalist species regarding definitive host. No significant differences were found when comparing richness, prevalence and abundance data of helminth species with respect to the sex of the host.

The helminth fauna of *M. martes* was also studied in each of four geographical areas. Qualitative and quantitative data for each host's subpopulations considered are shown in Table II. Diversity indexes are summarized in Table III for each component community. The greatest richness was detected in the Cantabrian Mountains' population in contrast with the least rich of Majorca. Table IV summarizes the results of similarity indexes for helminth communities found in pairwise geographical areas. Comparisons between geographical areas were also conducted by means of multivariate cluster analysis using the Jaccard coefficient and mean average linkage. The result of such analysis is represented in Figure 3.



**Fig. 3.** Similarity between helminth communities found in each subpopulation analysed. Cluster analysis was done using Jaccard coefficient and group average linkage

## Discussion

### Faunistic analysis

*Martes martes* exhibits in Spain a helminth fauna mainly constituted by nematodes, among which, the most prevalent and abundant species are included. The majority of helminths were extracted from the digestive tract, although the three predominant species (*P. plica*, *E. aerophilus* and *A. putorii*) were obtained from renal, respiratory and digestive (stomach) microhabitats, respectively.

The majority of helminth species found (82.35%) involved at least one intermediate host, which must be ingested by the carnivore to bring about the adult stage. This result is in agreement with studies of food habits carried out in Spain, as Cheylan (1984), Moreno *et al.* (1988), Ruiz-Olmo and Nadal (1991) and Clevenger (1993), and seem to indicate that diet is the key factor in determining the qualitative composition of helminth communities of *M. martes*.

*Euryhelms squamula* was the only trematode species found in our study. The finding of four adult individuals parasitizing one pine marten from CM constitutes a new host record for the species. The last intermediate host of *E. squamula* is *Rana temporaria*, which is frequently infested by the digenid above an altitude of 2,000 m (Combes *et al.* 1974). This assertion is in agreement with our findings.

*Taenia martis* is the only cestode species parasitizing *M. martes* in Spain. Except for Majorca, where the species was absent, this taeniid presented low frequencies and intensity values throughout the samples. *Clethrionomys glareolus* and *Microtus agrestis* are the only known intermediate hosts for *T. martis* in Iberia (Cordero del Campillo *et al.* 1994, Feliu *et al.* 1997). Given that both rodent species are absent in Minorca, the finding of the cestode in pine martens from this island reveals that some other rodent species (belonging to the Muridae or Gliridae family) could act as intermediate hosts for *T. martis*.

Fourteen species of nematodes were found parasitizing *M. martes* in Spain. Excluding the ascarid *B. columnaris* and the species of genus *Trichinella*, these can be clustered into four groups: trichurids (3 species), trichostrongylids (2), metastrongylids (3) and spirurids (4).

Species of the genus *Trichinella* have been previously reported parasitizing *M. martes* in the Iberian Peninsula (Cordero del Campillo *et al.* 1994). The results of our study indicate that this infection affects only pine martens from mainland areas. The predominance of trichurid species in the component helminth community was observed as much in general sample as in the corresponding subsamples (Tables I and II). The infection by the three trichurid species can occur via an earthworm, although in the case of *A. putorii* direct transmission has also been reported (Anderson 2000). This could be the main reason for the significant co-occurrence ( $p < 0.01$ ) found among *E. aerophilus*/*A. putorii* and *E. aerophilus*/*P. plica* in our general sample, and *E. aerophilus* and *A. putorii* in subsamples from PM (Table V).

**Table V.** Analysis of results: co-occurrence or specific species combinations of helminths in general sample (n = 102). Significant co-occurrences ( $p < 0.01$ ) are shaded

	Es	Tm	Pp	Ea	Ap	Tsp	Uc	Mp	Cp	Sp	Fm	Bc	Sl	Mm	Srs	Ps
Tm	0															
Pp	0	0														
Ea	0	2	8													
Ap	0	1	5	12												
Tsp	0	0	1	3	1											
Uc	0	0	0	0	0	0										
Mp	1	1	0	4	3	1	0									
Cp	1	0	1	6	5	2	0	2								
Sp	0	0	0	2	0	0	0	1	0							
Fm	0	0	2	2	3	0	0	1	1	0						
Bc	0	1	2	2	0	1	0	0	0	0	0					
Sl	0	0	0	0	0	0	0	0	0	0	0	0				
Mm	0	0	0	1	0	0	0	0	0	0	0	0	0			
Srs	0	1	0	2	0	0	0	0	0	1	0	0	0	0		
Ps	0	0	1	2	1	0	0	0	0	0	0	1	0	0	0	
Ca	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0

The trichostrongyloids *Uncinaria criniformis* and *M. patens* develop direct life cycles (Anderson 2000). The finding of the ancylostomatid in one pine marten from Minorca constitutes the first record of the species in *M. martes* from Spain. On the other hand, *M. patens* seems to affect pine martens from Majorca in particular.

The metastrongyloids and spiruroids detected in our study always require an invertebrate as intermediate host to complete their life cycles, even if additional paratenic hosts may be involved in the life cycle of some species. An examination of prevalence and mean abundance in the general sample showed moderately low values for *C. petrowi*, although in some areas (such as CM) the species seems to parasitize a significantly higher number of hosts. Both species are here reported for the first time parasitizing pine martens from Spain.

*Spirocerca lupi* is a species characteristic of canids which finding constitutes a new host record for *M. martes*. *Mastophorus muris* is a cosmopolitan nematode frequently found in rodents and insectivores (Torres *et al.* 1992, Portoles *et al.* 2000, Milazzo *et al.* 2003, Fuentes *et al.* 2004). Nevertheless, this spirurid was never reported in *M. martes* until now. The only pine marten found parasitized by *M. muris* may have acquired the infection by eating some of the great variety of insect species that can act as intermediate host for the spirurid (Anderson 2000).

*Spirura ritipleurites seurati* is a species characteristic of hedgehogs (Gafurov and Isakov 1970). The intermediate hosts of this species (mainly beetles) are usually found in food studies carried out on *M. martes* in the Balearic Islands (Moreno *et al.* 1988, Clevenger 1993). This finding remains significant, since it constitutes a new host record for the species.

*Physaloptera sibirica* has been recently reported by Torres *et al.* (2001) parasitizing other mustelid species as *M. meles* in the Iberian Peninsula. Its distribution seems to be limited to geographical areas of high altitude and cold climate, as it was

similarly apparent in other Spanish studies in which the species was found parasitizing foxes (Miquel *et al.* 1996, Segovia *et al.* 2004).

*Centrorhynchus aluconis* was found in three pine martens from Majorca, which constitutes the first report in the mustelid. Some species of amphibians, reptiles and small mammals can act as intermediary hosts for the acanthocephalan (Ewald *et al.* 1991, Cordero del Campillo *et al.* 1994).

#### Ecological analysis

The analysis of general distribution of abundance data show great differences between species found. As can be seen in Table I and Figure 2, the helminth community found in *M. martes* can be considered made up by two group of species clearly differentiate. The first set encompasses a small number of species (*P. plica*, *E. aerophilus* and *A. putorii*) showing the highest values of prevalence and mean abundance. On the other hand, the second set encompasses a larger number of species which values of prevalence and mean abundance are very much lower. This fact can be clearly appreciated by examining the distribution of percentage of abundance for species found that seems to indicate a high predominance of only a few species (Fig. 2). A similar trend was observed after examining data of frequencies.

All of the above findings allowed us to conclude that helminth communities of *M. martes* show, in general, a bimodal pattern in Spain consistent with the classification proposed by Hanski (1982, 1991) for core and satellite species. The set of dominant species would be composed of the trichurids *P. plica*, *E. aerophilus* and *A. putorii*, while the remaining would be satellite species (Table I). In certain geographical areas, some dominant species could be replaced with others demonstrating locally elevated prevalence and abundance data. For example, it can be observed the significantly high prevalence found in CM for *C. petrowi* ( $\chi^2 = 4.50$ ;

$p < 0.05$ ), in contrast with the significantly lower values found for *E. aerophilus* ( $\chi^2 = 4.50$ ;  $p < 0.05$ ), which also parasite the respiratory system of *M. martes* (Table II).

Examinations of the biology and host specificity for the studied helminth species evidence the generalist food habits of the mustelid, since all core species have indirect life cycles, with two of them (*P. plica* and *E. aerophilus*) being generalists with respect to the definitive host. Then again, a study of helminth community diversity showed slightly different values regarding the geographical areas considered (Table III).

Given the carnivore-like character of the mustelid, as well as the finding that a majority of helminth species have an indirect life cycle, helminth communities of higher diversity would be expected in those areas where pine martens have a more varied food spectrum. In contrast, slightly higher diversity values for helminth communities from the Pyrenean Mountains and Majorca could be discerned, while those from the Cantabrian Mountains and Minorca showed a higher dominance of certain helminth species. Such information must be considered only in a prospective way, since the different size of the subsamples could exert a strong influence over the value of indexes.

Considering that sample size represent an important factor influencing the number of helminth species detected, is surprisingly the great diversity found in PM, where the sample was very small. This finding contrasts with the results published by other authors affirming that fruits are the most important food item (93%) of the marten's annual diet in the PM (De Marinis and Masseti 1995).

The index of Margalef is a measurement of richness that allowed us to eliminate the effect of size sample. In our case, the clearly higher values obtained for helminth communities found in Minorca are in accordance with the study by Clevenger (1993), which reported a wider food niche breadth for pine martens in the insular environment compared to the mainland populations. On the other hand, similarity measures (Table IV) and cluster analysis (Fig. 3) allowed us to observe the highest similarity between helminth communities found in mainland areas, while those found in island areas seemed to show particular characteristics.

Only one species (*E. aerophilus*) was detected everywhere, whereas the 41.2% represents sporadic findings (see Table II). This fact suggests certain specificities regarding the helminth communities found in the four *M. martes* subpopulations. Majorca showed the most depauperate helminth fauna, even though two of the helminth species found (*Sobolevinskyus petrowi* and *Centrorhynchus aluconis*) seem to be restricted to this island. The number of helminths detected in Minorca (8 species) proved higher than in Majorca, probably due to the large number of specimens analysed, with two other species (*Uncinaria criniformis* and *Mastophorus muris*) seemingly limited to this island. *Spirura rytipleurites seurati* is another helminth restricted to the insular population of *M. martes*, although in this case it was detected in both islands.

On the mainland, the helminth community of *M. martes* proved richer than in the Gymnesic islands, being composed of twelve species (seven of them found in both CM and PM). The majority of these species (*E. squamula*, *Trichinella* sp., *F. martis*, *B. columnaris*, *S. lupi* and *P. sibirica*) have been exclusively detected in the mainland.

A comparative analysis of frequencies for the five species found in both CM and Minorca subpopulations (*T. martis*, *P. plica*, *E. aerophilus*, *A. putorii* and *C. petrowi*) demonstrated the existence of significant differences ( $p < 0.05$ ) in most of them (*E. aerophilus*, *A. putorii*, *C. petrowi*;  $\chi^2 = 4.5$ , 6.4 and 23.15, respectively). Significant differences were also found in comparisons of abundances values for these same species.

The 'Theory of Insular Biogeography' developed by MacArthur and Wilson (1967) can be applied in analysing the relationship between certain geographical factors, such as the surface of the islands or the distance from the mainland in regard to the number of living species. Generally, larger islands harbour a greater number of parasitic species, although there are many exceptions to this rule (Mas-Coma *et al.* 1987). In this context, several authors did not reveal any correlation between island size and helminth diversity, concluding that the particular conditions of each island may involve several factors that determine the composition of parasitic faunas (Kennedy 1978, Dobson *et al.* 1992).

In general, the helminth communities found in the individual hosts from the islands prospected in our study showed richness values slightly higher than those stemming from mainland areas. This fact is in contrast with the absence of some helminth species, such as *E. squamula*, *Trichinella* sp., *F. martis*, *B. columnaris*, *S. lupi* and *P. sibirica*, in *M. martes* from islands areas (Table II). On the other hand, among the species found exclusively in insular pine martens, these species could be considered endemic in the context of the 'Theory of Island Biogeography'.

Although no significant relation between helminth diversity of the four studied *M. martes* subpopulations and their home range exists, diversity values seem to increase with geographical range, which could be interpreted as consistent with MacArthur and Wilson's theory of insularity (1967). These results can also be due to several factors other than insularity, which may affect both richness and helminth diversity of the pine marten (diet, density of population, ethology and cohabitation with other mustelid species, mainly with *M. foina*). In both Majorca and Minorca, the only other living mustelid alive besides the pine marten is the weasel, *Mustela nivalis*, whereas in the CM and PM areas *M. martes* lives together with many other mustelids. This fact can also explain the higher richness found for helminth communities from mainland areas, since cohabitation factors can contribute to the maintenance of life cycles for some species not found on these islands.

In light of the above findings, the helminth fauna found in *M. martes* reveal the markedly carnivore-like character of the mustelid, which show similar helminth communities of other

Iberian mustelids with analogous feeding patterns and habitats. Pine martens from mainland areas have a more diverse helminth fauna, which could be due to their cohabitation with other mustelids, or a more varied food spectrum. In addition, the results of our study demonstrate the great importance of earthworms within the diet of pine marten, mainly affecting individuals from mainland areas, where capillariid species diversity remains higher. These findings contribute to the knowledge of the pine marten's food ethology, since this kind of prey normally goes undetected in diet studies.

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